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The Center for Night Vision and Electro-Optics

OPTOELECTRONIC WORKSHOPS (14th)

XIV

FERROELECTRIC LIQUID CRYSTAL IR CHOPPER

February 21, 1989

sponsored jointly by

ARO-URI Center for Opto-Electronic Systems Research
The Institute of Optics, University of Rochester

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FIELD	GROUP	SUB-GROUP	

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

This workshop is a follow-up to Workshop IV: Liquid Crystals for Laser Applications, which was held at NVEOC on May 11, 1988. At the original meeting it was agreed that Rochester would initiate a project to study methods for developing a nonmechanical IR chopper using liquid crystal technology. At this meeting a progress report was given to Infrared Technology Division (IRT) members of the Uncoded Devices Development Team (UDDT). Preliminary results demonstrated that submillisecond response for a ferroelectric liquid crystal chopper in the transient light scattering mode (TLSM) is possible. It was agreed that experiments should now examine the transmission limits and forward scattered optical radiation distributions in thin cells, with possible work to establish that a square wave transmitted energy profile can be achieved.

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The Center for Night Vision and Electro-Optics

OPTOELECTRONIC WORKSHOPS

XIV

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OPTOELECTRONIC WORKSHOP

ON

FERROELECTRIC LIQUID CRYSTAL IR CHOPPER

Organizer: ARO-URI-University of Rochester
and Center for Night Vision and Electro-Optics

1. INTRODUCTION

2. SUMMARY -- INCLUDING FOLLOW-UP

3. VIEWGRAPH PRESENTATIONS

   A. Center for Night Vision and Electro-Optics
      Organizer -- James E. Miller

      A Review of the IR Chopper Issues
      James E. Miller

   B. Center for Opto-Electronic Systems Research
      Organizer -- Stephen Jacobs

      IR Shutter-Chopper Employing Ferroelectric Liquid Crystals
      Kenneth L. Marshall

4. LIST OF ATTENDEES

5. APPENDIX

   Feasibility Study Report, "IR Shutter-Chopper Employing Ferroelectric Liquid Crystals," by K. L. Marshall and S. D. Jacobs

1. INTRODUCTION

This workshop is a follow-up to Workshop IV: Liquid Crystals for Laser Applications, which was held at NVEOC on May 11, 1988. At the original meeting it was agreed that Rochester would initiate a project to study methods for developing a nonmechanical IR chopper using liquid crystal technology. At this meeting a progress report was given to Infrared Technology Division (IRT) members of the Uncoded Devices Development Team (UDDT). Preliminary results demonstrated that submillisecond response for a ferroelectric liquid crystal chopper in the transient light scattering mode (TLSM) is possible. It was agreed that experiments should now examine the transmission limits and forward scattered optical radiation distributions in thin cells, with possible work to establish that a square wave transmitted energy profile can be achieved.

2. SUMMARY AND FOLLOW-UP ACTIONS

Rochester presented data for two ferroelectric liquid crystal blends which demonstrated that a scattering state could be induced and removed in 25 µm thick glass cells in less than 1 millisecond. The measurements were conducted at 632 nm.

NVEOC members emphasized that, for the liquid crystal technology to be competitive with mechanical choppers, Rochester should concentrate on the following (in order of priority):

1. Determine transmissivity limits for thin (25-50 µm) elements in the clear state between the wavelengths of 8 µm and 12 µm, using in-house and commercial ferroelectric materials.

2. Characterize the induced forward scattering effect for magnitude, direction, and sensitivity to polarization in the infrared with assistance of NVEOC personnel.

3. Demonstrate millisecond square wave optical response.

CENTER FOR NIGHT VISION AND ELECTRO-OPTICS
LIQUID CRYSTAL ELECTRO-OPTIC SHUTTER

LIQUID CRYSTAL E-O SHUTTER

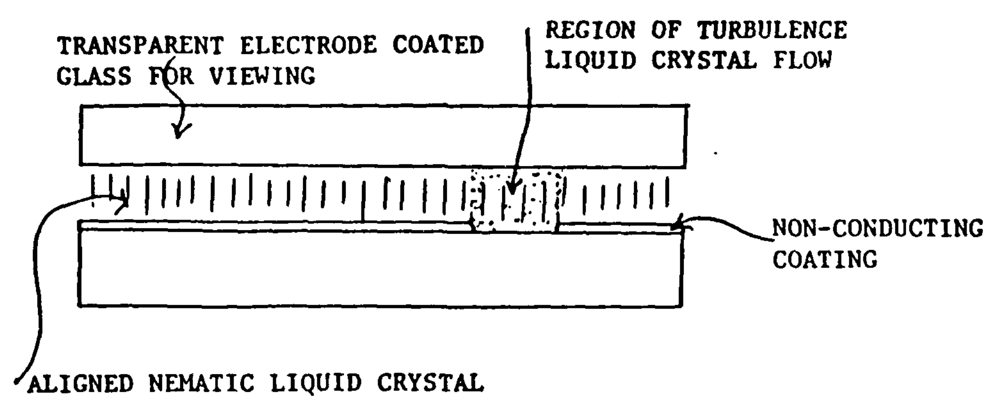
- BACKGROUND
  - NEED FOR CHOPPER
  - PRESENT SOLUTIONS
    - METAL TOOTH WHEEL: ON/OFF
    - GERMANIUM SPIRAL: FOCUS/DEFOCUS
    - DISADVANTAGES
- PROPOSED SOLUTION
  - LINE SCAN CHOPPER
    - DESIRED FEATURES
    - PRINCIPLE OF OPERATION
  - PROGRESS: DR I. C. KOO, PENN. STATE
- CONCLUSIONS
  - PROBLEMS
  - APPROACHES

LINE SCAN CHOPPER-DESIRED FEATURES

- OPERATES BY FORWARD SCATTERING, NOT TRANSMISSION REDUCTION
- WIDE ACCEPTANCE ANGLE: 40° FULL ANGLE
- ELECTRICALLY LINE ADDRESSABLE
- LARGE ARRAY SIZE: 0.5" SQUARE
- LINE WIDTH: <100 MICRON
- LOW INSERTION LOSS: $<20\%$
- BROADBAND OPERATION: 8-12 MICRON
- SWITCHING TIME: <1 ms, ON AND OFF
- FORWARD SCATTERING: $>95\%$ INTO ANNULUS 10 LINES DIAMETER
- OPERATING TEMPERATURE: -20°C TO +50°C

PRINCIPLE OF OPERATION

- DYNAMIC SCATTERING IN NEMATIC LIQUID CRYSTAL
- APPLIED E FIELD INDUCES TURBULENT MOTION
- MOTION CAUSES OPTICAL SCATTERING



CONCLUSIONS

- TURN OFF TOO SLOW: 100 ms → 1 ms
  - SIZE EFFECTS
  - E FIELD EFFECTS
- FIELD CRYSTAL MIXTURE NEEDS OPTIMIZING
- ELECTRODE EFFECTS NEED CHARACTERIZING
- SCATTERING ANGLES NEED CHARACTERIZING
- MULTI-LINE CELL NEEDS DEMONSTRATION
  - INSERTION LOSS
  - IMAGE DEGRADATION
- IN GENERAL, PROMISING APPROACH

CENTER FOR OPTO-ELECTRONIC SYSTEMS RESEARCH
FERROELECTRIC LIQUID CRYSTAL IR CHOPPER

Mini-Workshop

IR Shutter-Chopper Employing Ferroelectric Liquid Crystals

UR LLE

Night Vision and Electro-Optics Center
Fort Belvoir, VA

21 February 1989

University of Rochester

Organizer
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Night Vision and Electro-Optics Center

Organizer
J. E. Miller
(703) 664-1585

Supported by the Army University Research Initiative Program at The Institute of Optics and the Laboratory for Laser Energetics of the University of Rochester

Electro-Optic Devices Based on Dielectric Effects in *Nematic* Liquid Crystals

- Wide application in information display area
  - low operating voltage
  - low power consumption
  - relatively easy to fabricate
  - good contrast in strong ambient lighting
- Disadvantages for high-speed optical processing/switching applications
  - slow response times (10–500 ms)
  - static electric field required to reorient and stabilize director (not bistable)
  - electro-optic response *not* field linear (strong threshold effect)

G1926

Ferroelectric Liquid Crystals
Advantages

UR LLE

- Fast response - 0.5 μs demonstrated, nanosecond response times predicted
- Bistable switching effect - pulsed dc drive
- Optic axis orientation determined by polarity of applied electric field
- Field-linear E-O response possible under certain conditions
- Large E-O response for thin cell spacings

G2319

Origin of Ferroelectric Effects in Chiral Smectic Liquid Crystals

UR LLE

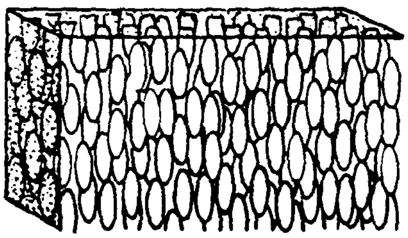
Ferroelectric Materials: defined as materials that over a certain temperature range possess a spontaneous polarization (or net dipole moment per unit volume), which is reversible by an external electric field

Dipolar ordering can arise in any system having a layered structure, tilt, and chirality of its constituent molecules
(R. B. Meyer, Harvard University, 1975)

Chiral smectic liquid crystals fulfill these requirements.

G1927

Diagram 1



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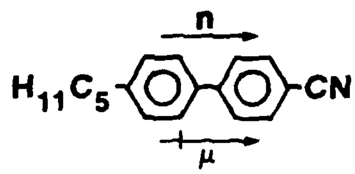

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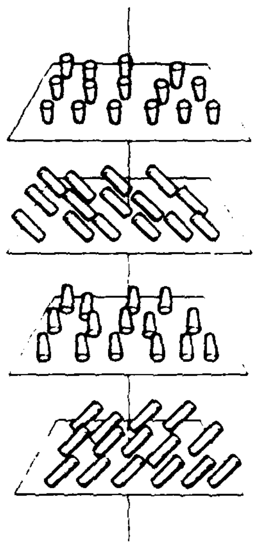

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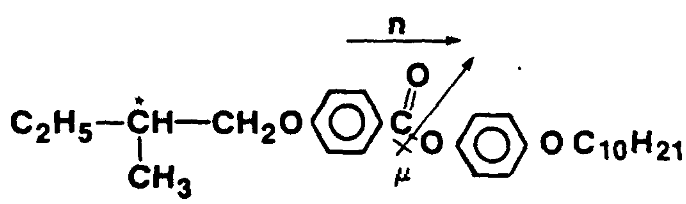
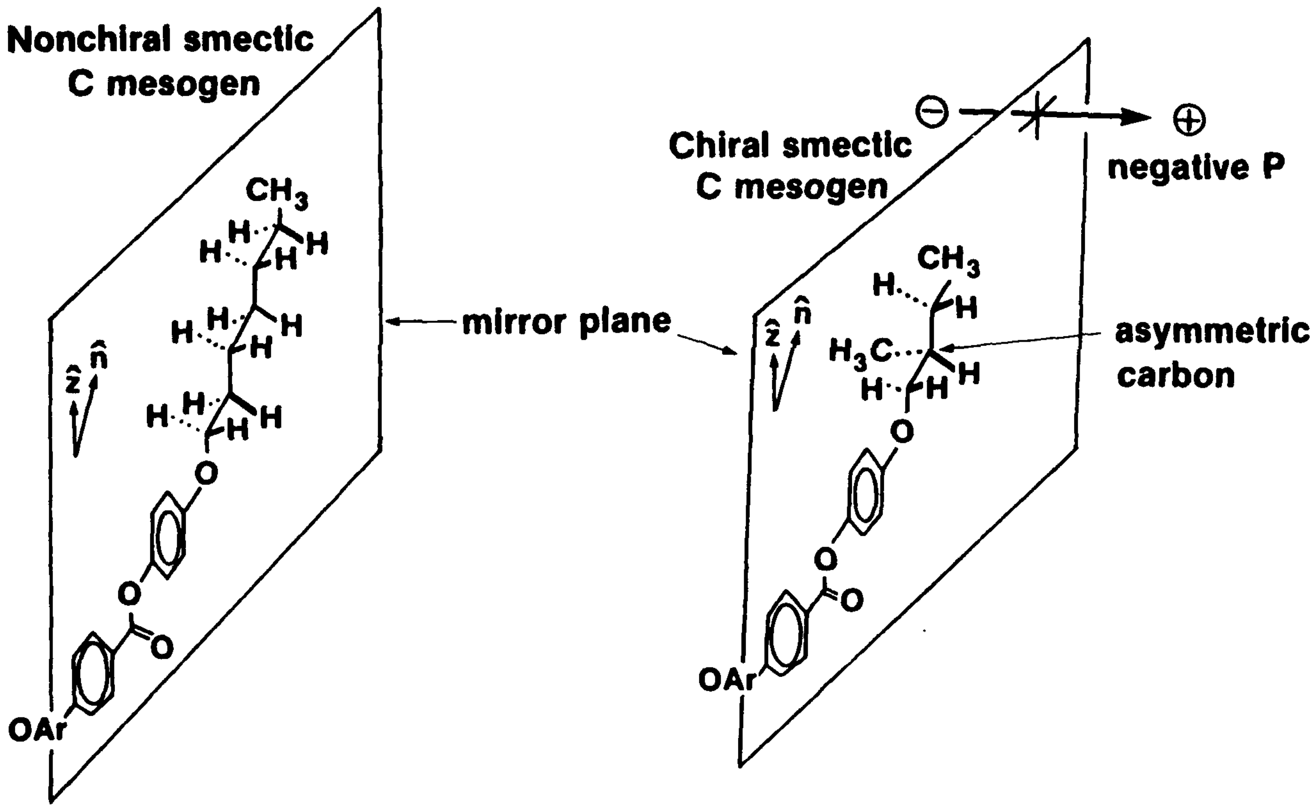


(d)

G1960

Chiral Centers Cause Spontaneous Formation of Permanent Dipoles by Reducing Molecular Symmetry

UR LLE

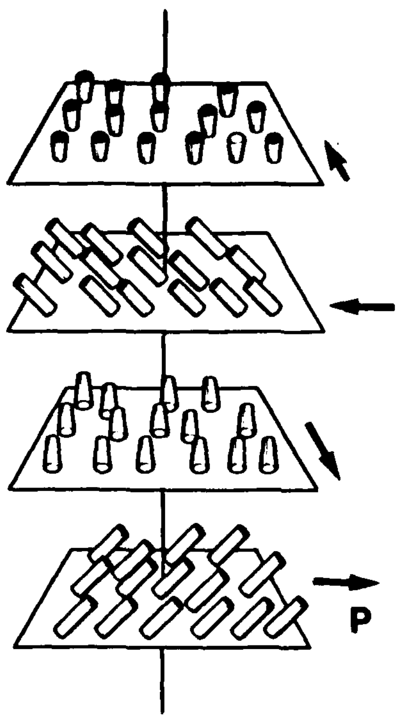


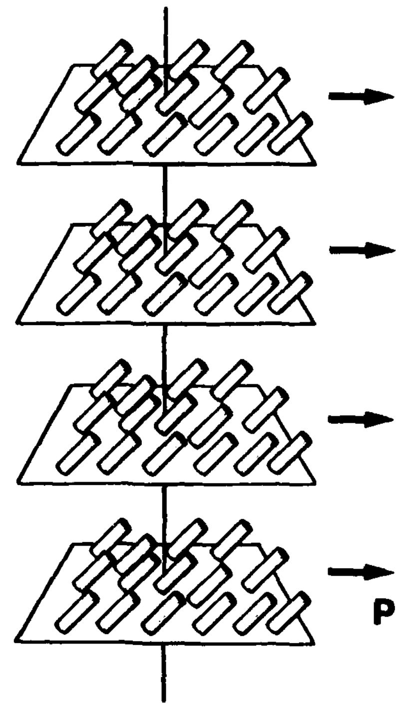
Walba *et al.*, *J. Am. Chem. Soc.* 108, 5217 (1986).

G1929

Chiral Smectic Liquid Crystals Must be Untwisted to Show Ferroelectric Properties

UR LLE





(a) twisted structure
net average dipole moment = 0
no bulk ferroelectric properties.

(b) untwisted structure
nonzero average dipole
ferroelectric properties exhibited.

G1932

Current Status of Ferroelectric Liquid-Crystal-Technology

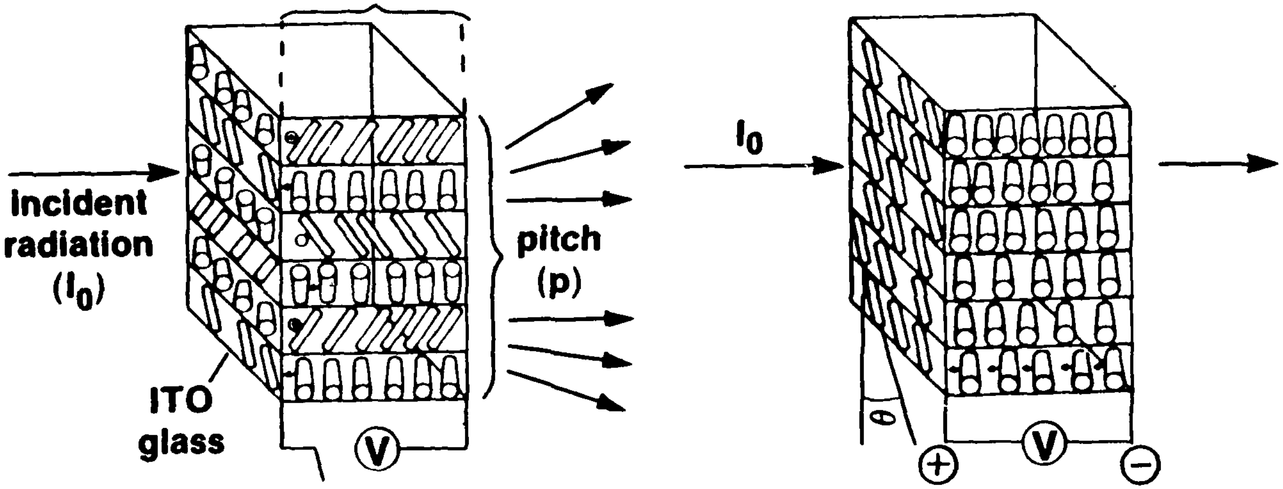
UR
LLE

Two Types (FLC and SSFLC): Differ in cell thickness
and degree of bistability

- Ferroelectric liquid-crystal devices (FLC)
  - cell thickness > pitch length; nonbistable
  - two switching mechanisms:
    1. helix unwinding in tight-pitch materials
    2. polarity reversal in field-untwisted cells

G1990

Helix Unwinding in Tight-Pitch Materials



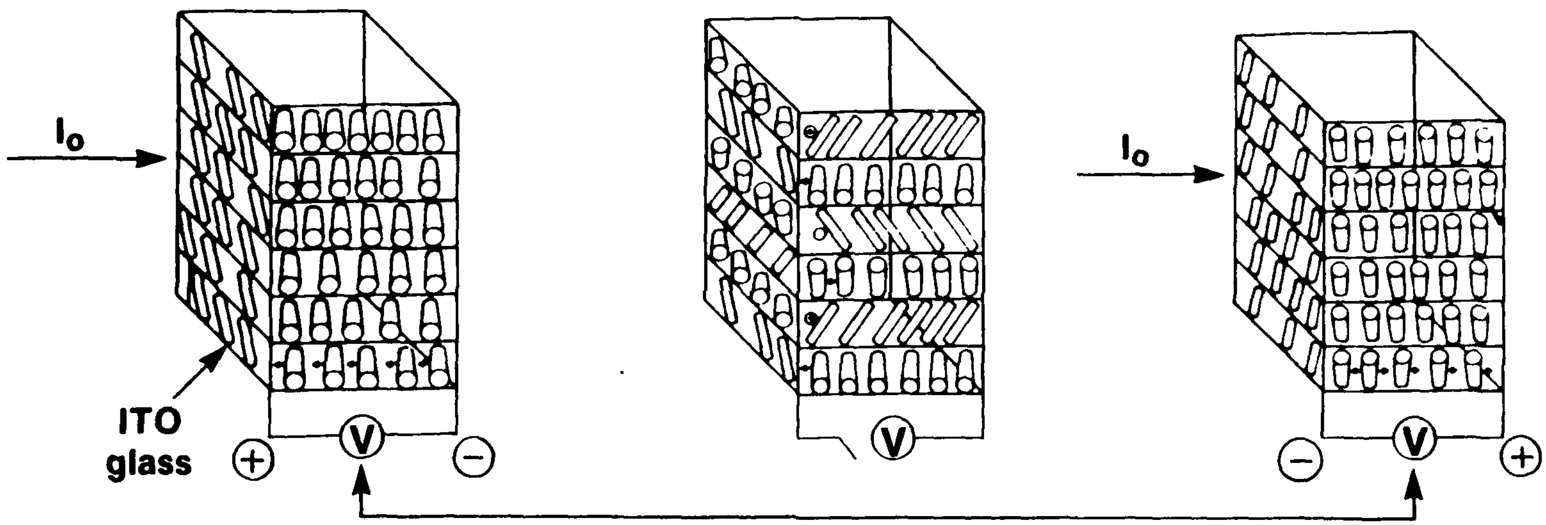
V = O - high scattering

$V > \pm V_{th}$ - transparent

- incident light polarized or unpolarized
- slow response

G1993

Polarity Reversal in Field-Untwisted Cells



- polarized incident light required
- change in field polarity reorients optic axis
- relaxes to twisted state in absence of field
- microsecond response possible

G1994

Key Issues for TLSM Shutter-Chopper Device Concept

UR LLE

- Does the TLSM mode in ferroelectric liquid crystals have sufficiently fast rise and decay times to be useful in the proposed device?

- Are there mid-infrared transmission windows in these materials at or near wavelengths of interest?

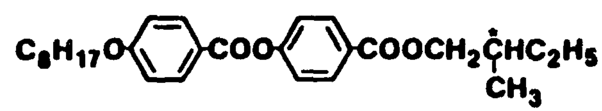
G2567

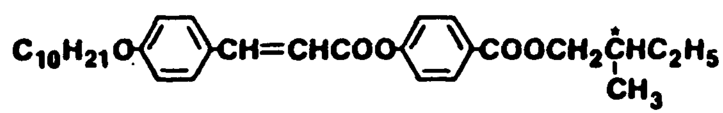
Chiral Smectic C Mixtures Used for SSFLC Alignment Studies

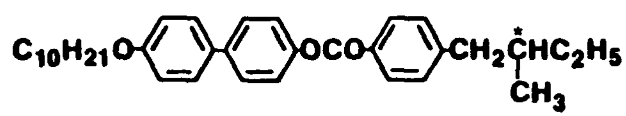
Mixture ID: G-1456

Source: Components prepared in-house, mixed according to literature formulation

Tilt angle class: low tilt material

(XIV)  17%

(XV)  55%

(XVI)  28%

$\mathrm{Iso} \xleftrightarrow[97]{} S_A \xleftrightarrow[50]{} S_C$ m.p. 10, calc. 14

m.p.	calc.
10	14

J. W. Goodby and T. M. Leslie, *Mol. Cryst. Liq. Cryst.* 110, 175-203 (1984).

Electro-Optic Response Characterization

Cell Assembly:

- ITO-coated glass substrates (25 mm x 25 mm x 3 mm thick) treated with rubbed polymer layer to establish initial liquid crystal orientation
- Two ferroelectric, liquid crystal mixtures investigated:
  - G-1456 (formulated in-house)
  - ZLI-4003 (E. M. Laboratories)
- Two cells prepared with each mixture at path lengths ranging from 12–50 μm (Mylar spacers)
- No attempt made to optimize alignment quality or make adjustments in mixture compositions that would maximize birefringence or spontaneous polarization

G2568

MERCK
E.MERCK DARMSTADT

ZLI-4003

PRELIMINARY DATASHEET

FERROELECTRIC SMECTIC MIXTURE

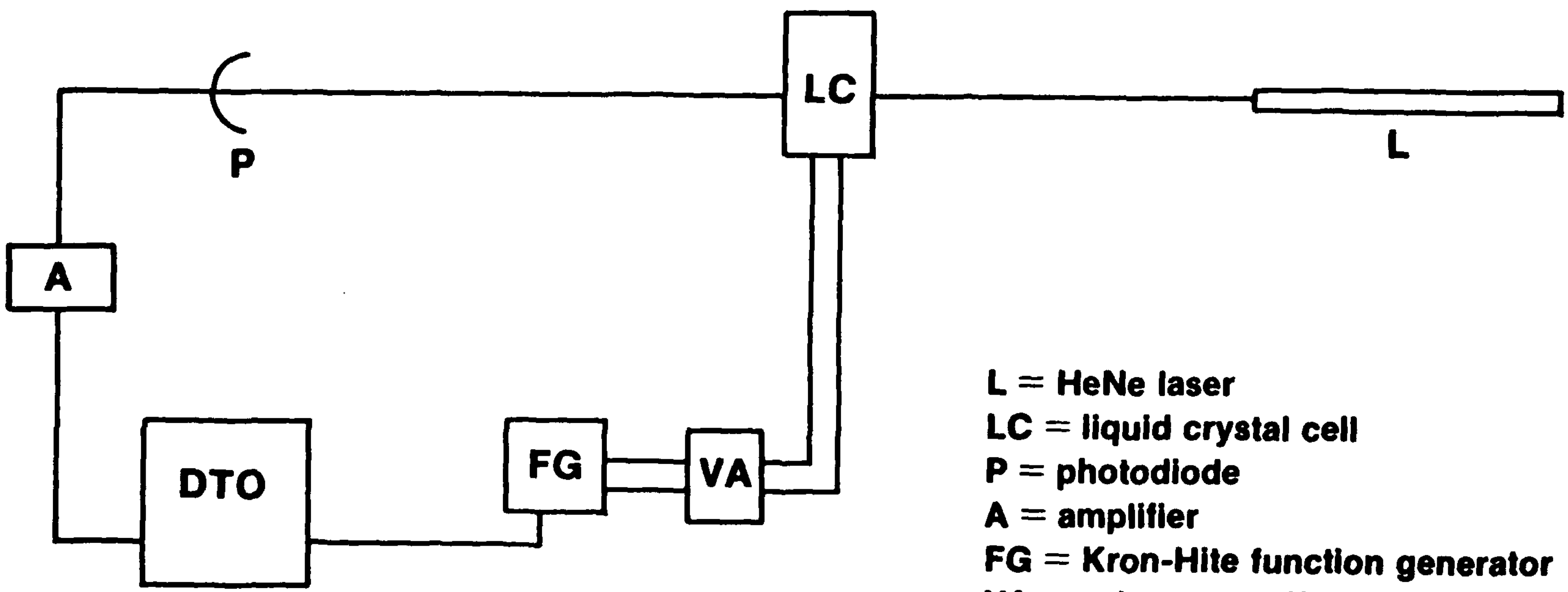
PROPERTIES:

PHASES AND TRANSITION TEMPERATURES
K <-20 SmC* 62 SmA 76 Ch 85 I ℃

SPONTANEOUS POLARIZATION (20 ℃)		-20.2 nC/cm²
TILT ANGLE (20 ℃)	θ	23.0 °
HELICAL PITCH IN SMECTIC PHASE (20 ℃)		-3 μm
HELICAL PITCH IN CHOLEST.PHASE (79 ℃)		-9 μm
SWITCHING TIME (20 ℃ ,15 V/μm)	τ	39 μs
ROTATIONAL VISCOSITY (20 ℃)	γ	173 mPas
OHMIC RESISTIVITY (20 ℃)		>1E10 Ωcm
Δn_d		0.13

Rev.: 11 Sep 1987 Rev.: 11 Sep 1987

Electro-Optic Test Setup

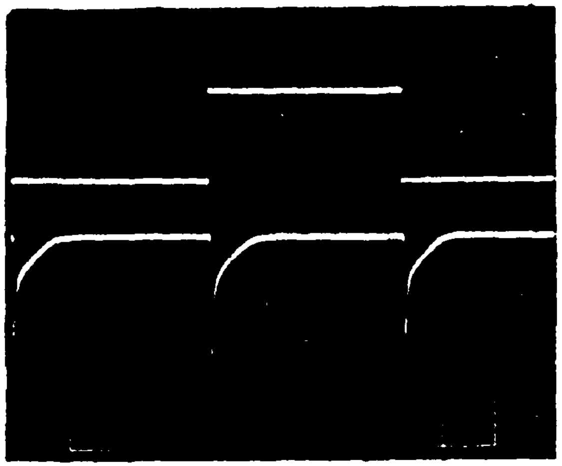


L = HeNe laser
LC = liquid crystal cell
P = photodiode
A = amplifier
FG = Kron-Hite function generator
VA = voltage amplifier
DTO = dual-trace oscilloscope

G2571

TLSM Response in ZLI-4003

(a)



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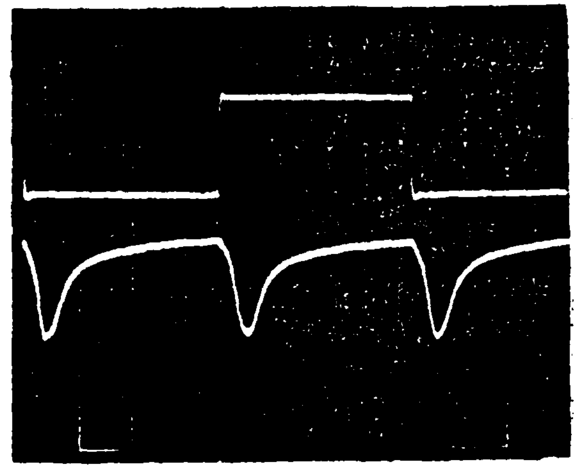
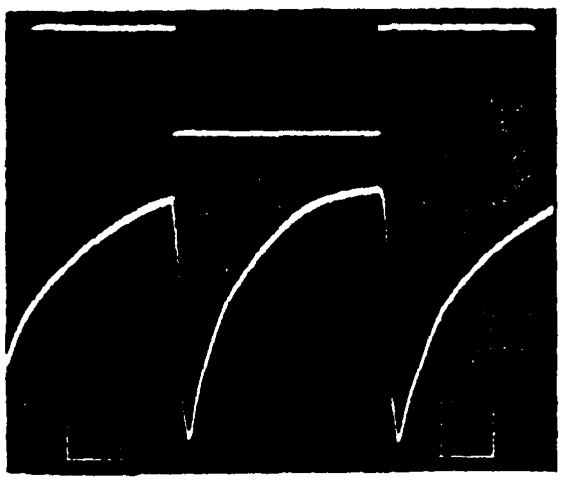


Cell I
pathlength: 25 μm

a. drive voltage: 200 V
time axis: 2 ms/div

b. drive voltage: $\pm$200 V
time axis: 200 μs/div

(c)



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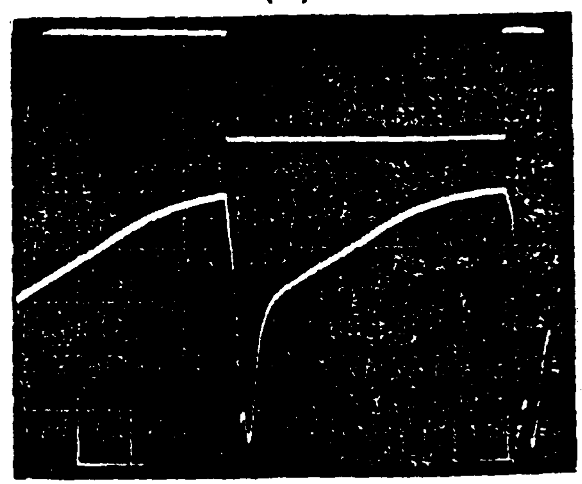


Cell III
pathlength: 50 μm

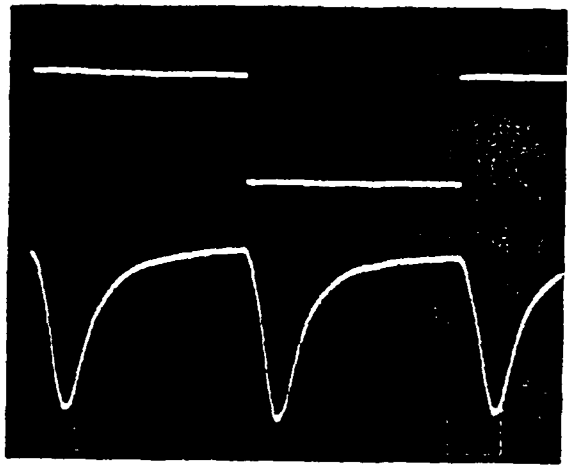
c. drive voltage: $\pm$80 V
time axis: 2 ms/div

d. drive voltage: $\pm$200 V
time axis: 500 μs/div

G2578

TLSM Response in G-1456

(a)



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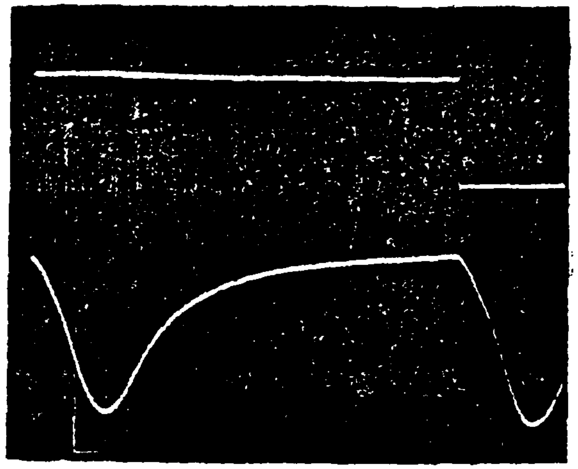
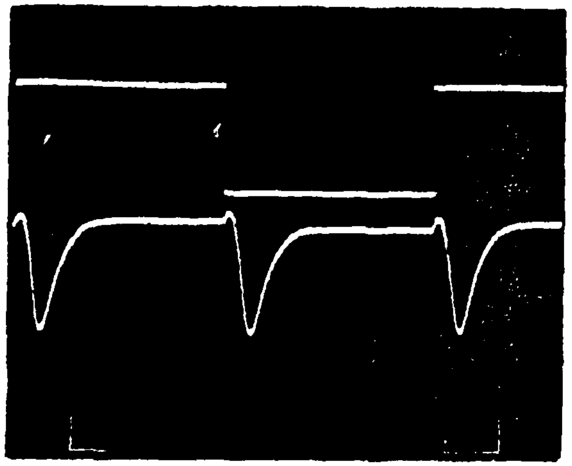


Cell II
pathlength: 25 μm

a. drive voltage: $\pm$200 V
time axis: 2 ms/div

b. drive voltage: $\pm$200 V
time axis: 1 ms/div

(c)



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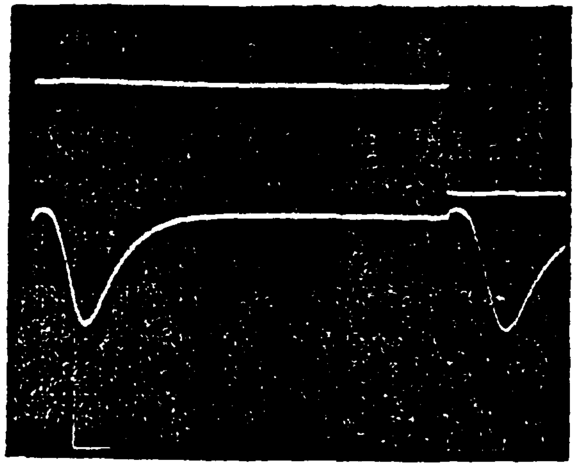


Cell IV
pathlength: 12 μm

c. drive voltage: $\pm$200 V
time axis: 2 ms/div

d. drive voltage: $\pm$200 V
time axis: 1 ms/div

G2577

TLSM-Mode Electro-Optic Response Characteristics of Ferroelectric Liquid Crystals

Cell	Material	Path Length	Rise Time	Decay Time
I	ZLI-4003	25 μm	80–100 μs (±200 V)	600 μs
II	G-1456	25 μm	1.2 ms (±200 V)	6 ms
III	ZLI-4003	50 μm	200 μs (±200 V)	6 ms
			1 ms (±80 V)	>8 ms
IV	G-1456	12 μm	800 μs (±200 V)	2 ms

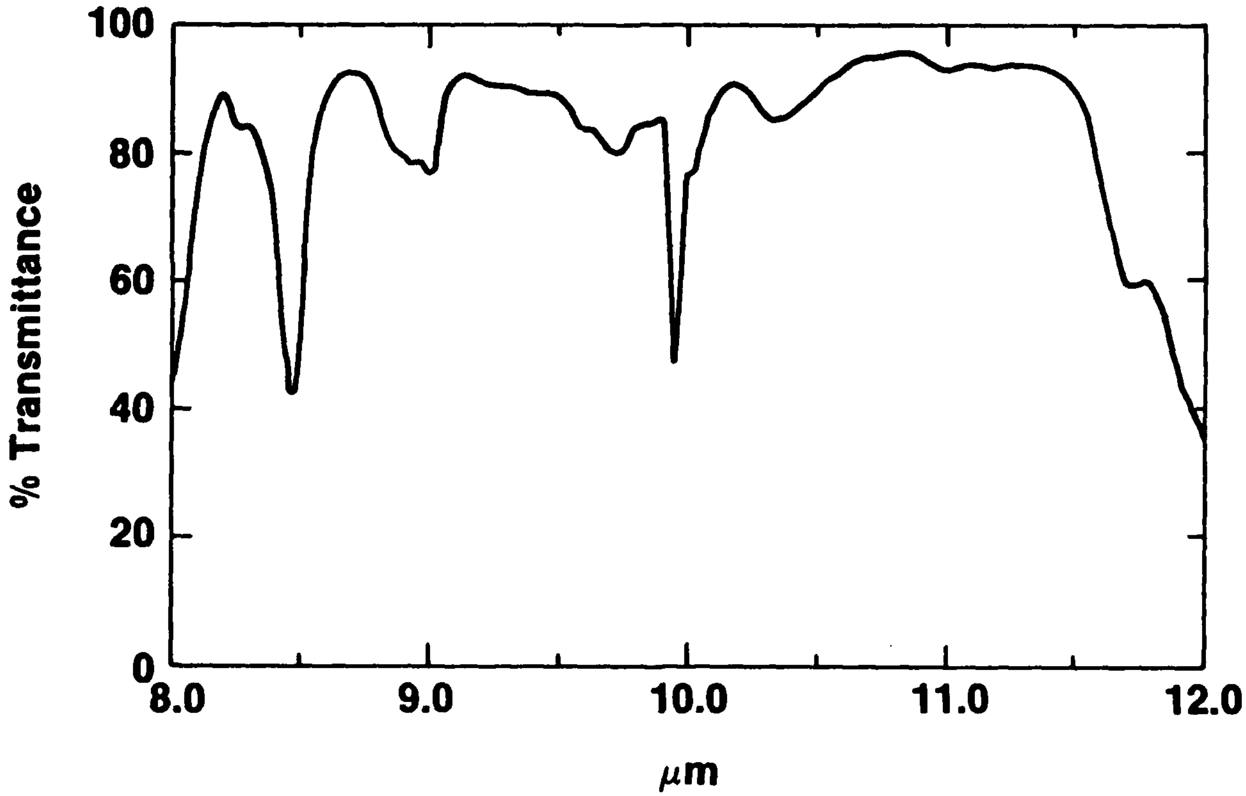
G2572

Infrared Transmission of Ferroelectric LCS

- Transmission values determined using a Wilks VR-6 variable-path infrared cell (uncoated KBr substrates)
- Liquid crystal material in chiral smectic-C phase
- Cell thickness = 10 μm; calibrated by interference fringe method
- All data corrected for Fresnel losses
- No alignment coatings used to promote uniform alignment

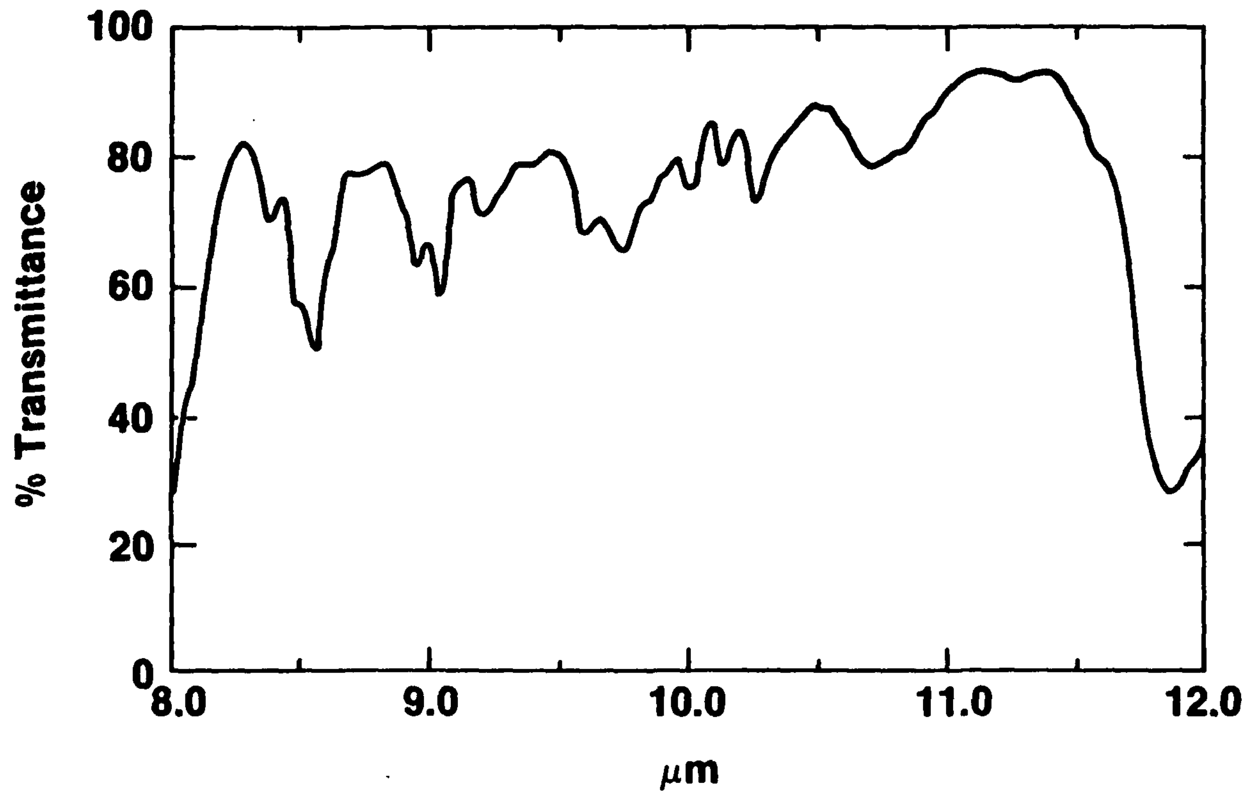
G2569

Infrared Transmission Spectrum of E-7



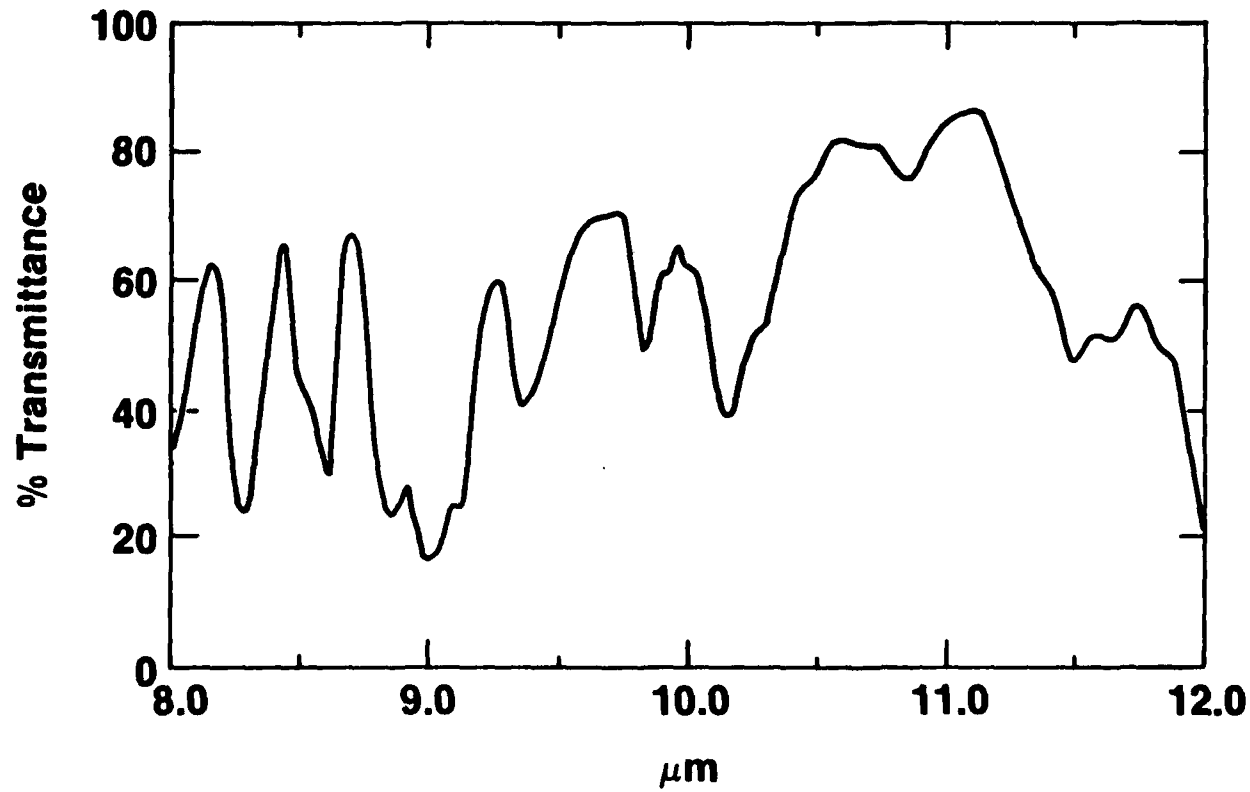
G2576

Infrared Transmission Spectrum of ZLI-4003



G2575

Infrared Transmission Spectrum of G-1456



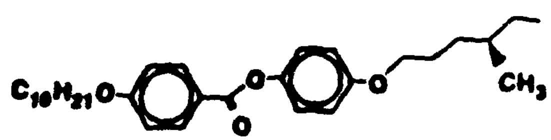
G2574

Chiral Smectic C Mixtures Used for SSFLC Alignment Studies

Mixture ID: DW-782

Source: Displaytech (compounds)
Displaytech formulation

Tilt angle class: Low tilt angle



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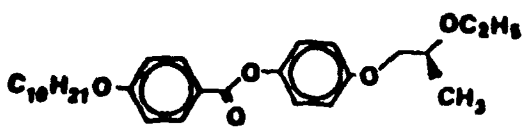


50 %

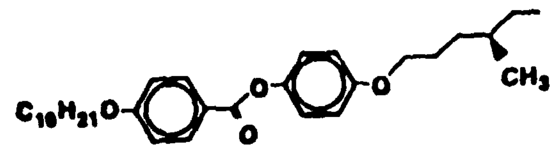
$I \overset{60}{\longleftrightarrow} S_A \overset{49}{\longleftrightarrow} S_c^* \overset{21}{\longleftrightarrow} S$

Comments: bulk crystallization occurs after ~ 1 wk

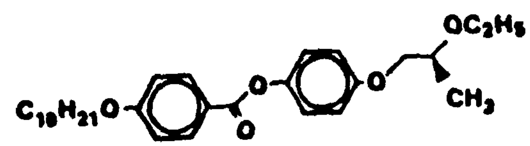
Mixture ID: DW-78182

Source: Displaytech (compounds)
Formulated in-house

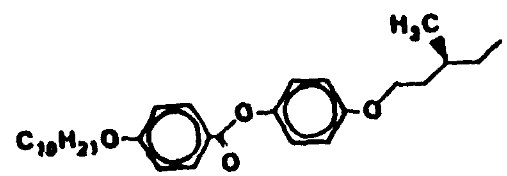
Tilt angle class: Low tilt angle



25 %



50 %

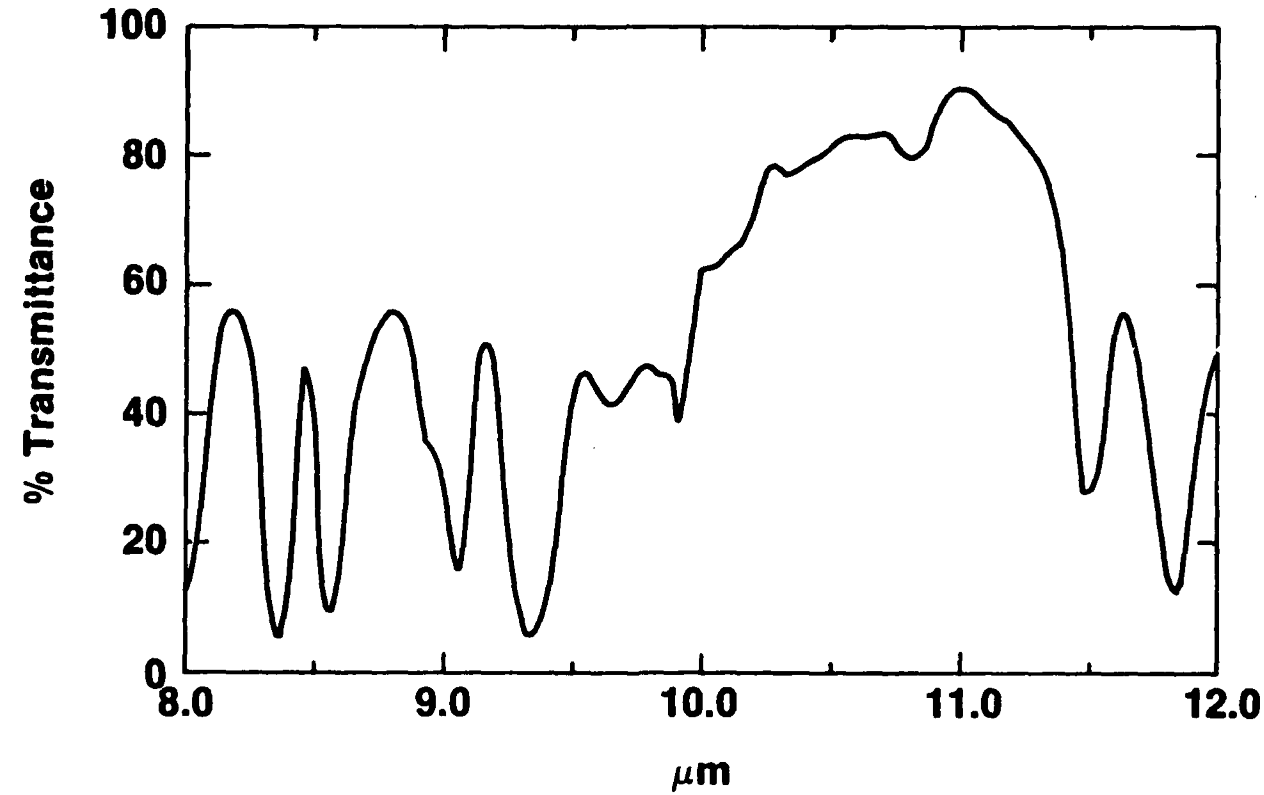


25 %

$I \overset{55}{\longleftrightarrow} S_A \overset{42.51}{\longleftrightarrow} S_c^*$ MP = below 20°C

Comments: bulk material stable for extended period (months): crystallization observed in cells stored at 20°C for several days

Infrared Transmission Spectrum of D-78182



G2573

Infrared Transmission of Unaligned Ferroelectric Liquid Crystal Mixtures at 10.6 μm

UR LLE

G-1456	81.8%
D-78182	82.9%
ZLI 4003	84.5%
E7 (Nematic)	94.0%

Cell path length = 10 μm

G2580

Areas for Future Investigation

- Improve decay time by pulse shaping
- Investigate effect of device on polarization of incident radiation
- Examine individual, ferroelectric, liquid crystal compounds for IR transmission and blend appropriate compounds into eutectic mixtures
- Improve alignment quality to minimize scatter in transmissive state
- Fabricate device on IR transparent substrates and evaluate mid-infrared performance
- Prepare new mesogens with improved mid-infrared transparency (long-term goal)

G2570

LIST OF ATTENDEES

4. LIST OF ATTENDEES

FERROELECTRIC LIQUID CRYSTAL IR CHOPPER

February 21, 1989

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APPENDIX

IR SHUTTER-CHOPPER EMPLOYING FERROELECTRIC LIQUID CRYSTALS

A Feasibility Study Conducted for:

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I. INTRODUCTION

During the past few months, we have been investigating the feasibility of using the transient light scattering mode (TLSM) in ferroelectric liquid crystal materials for the modulation of infrared radiation. The device concept is illustrated in Fig. 1. With no electric field applied, the ferroelectric liquid crystal helix axis aligns parallel to the confining substrates, which results in a scattering texture. The application of a DC field with a positive polarity causes the helix to unwind, rendering the device highly transparent. Reversal of the field polarity causes an immediate and rapid reversal of the liquid crystal domain structure, resulting in a momentary transition through the scattering state followed by restoration of the transmissive state. Because of the transient nature of the scattering effect and the strong coupling of the spontaneous polarization in ferroelectric liquid crystals to the applied electric field, response times in the microsecond regime can be anticipated. Our investigations to date have been primarily directed toward resolving two key issues of importance to the proposed device concept:

(1) Does the TLSM mode in ferroelectric liquid crystals have sufficiently fast rise and decay times to be useful in the proposed device, and

(2) Are there mid-infrared transmission windows in these materials at or near wavelengths of interest.

II. ELECTRO-OPTIC RESPONSE CHARACTERISTICS OF THE TLSM MODE

The initial evaluation of the electro-optic response of ferroelectric liquid crystals in the TLSM mode was conducted in the visible region in order to simplify the cell assembly and electro-optical measurement procedures. Since the mechanism for the electro-optic response in liquid crystal materials is independent of the wavelength of incident light, the response times obtained in the visible region experiments can be directly extrapolated to the infrared region. Ferroelectric liquid crystal test cells were prepared using 3 mm thick ITO coated glass substrates with an active area of 25 mm x 25 mm which were further treated with a rubbed polymer alignment coating to establish an initial director orientation. Two ferroelectric liquid crystal mixtures were selected for this initial study: ZLI 4003, a commercially available low-birefringence material, and G-1456, a medium birefringence material formulated in-house. Two cells of different fluid layer thickness were filled by capillary action at elevated temperature with each of the ferroelectric liquid crystal materials. Cell gap thickness was controlled by the use of Mylar spacers. Electro-optic response time measurements were conducted using the setup shown in Fig. 2. A helium-neon laser served as the light source. The driving waveform was supplied by a Kron-Hite function generator connected in series with an in-house assembled solid-state amplifier capable of greater than ±200 V output. The cell response was monitored by a photodiode and displayed on a dual-trace oscilloscope along with the driving waveform.

In Fig. 3, the electro-optical response curves for the 25- and 50-μm cells containing ZLI 4003 (Cells I and III) to applied square wave voltages of ±80 and ±200 V are shown. In the case of Cell I, the low birefringence of ZLI 4003 resulted in a rather weak induced scattering for a 25 μm path of this material. However, the electro-optic rise time response of this cell was extremely rapid (80–100 μs at ±200 V). Increasing the pathlength to 50 μm produced a much stronger optical response without drastically reducing the response time, as can be seen for Cell III in Fig. 3. The rise time for this cell varies from approximately 1 ms for a ±80 V square wave to 200 μs for the same waveform at ±200 V. Unfortunately, both samples exhibited a rather shallow decay curve, with the transmission gradually restored to its initial value within 600 μs to 6 ms, depending on cell thickness. Increasing the drive voltage had some effect on the shape of the decay curve [see Fig. 3(d)], but did not appear to substantially reduce the decay time.

The TLSM mode response for 25 and 12 μm paths of G 1456 (Fig. 4) exhibited a considerably slower rise time (800 μs - 1.2 ms at ±200 V) than that observed for the ZLI 4003 cells; however, the slope of the decay curves in G-1456 appeared to be much steeper than in ZLI-4003. A possible explanation of this phenomenon is that the shorter helix pitch length in G-1456 adds an additional elastic restoring torque not present in the long-pitch ZLI-4003, resulting in reduced decay times for this material. Little difference in decay time was observed between the two materials at the same cell thickness; however, reducing the cell thickness in from 25 μm (Cell II) to 12 μm (Cell IV) resulted in a reduction of the decay time from 6 ms to approximately 1.5–2 ms with a loss of about 1/3 of the original modulation depth. A similar reduction of thickness in the ZLI 4003 cells caused nearly 3/5 of the original blocking ability to be lost (see Fig. 3).

In Table I, the previously discussed results of the TLSM mode measurements for G-1456 and ZLI-4003 are summarized for ease of comparison.

TABLE I

TLSM MODE ELECTRO-OPTIC RESPONSE CHARACTERISTICS OF FERROELECTRIC LIQUID CRYSTALS

Cell	Material	Path Length	Rise Time	Decay Time
I	ZLI 4003	25 μm	80-100 μs (±200 V)	600 μs
II	G-1456	25 μm	1.2 ms (±200 V)	6 ms
III	ZLI 4003	50 μm	200 μs (±200 V)	6 ms
			1 ms (±80 V)	>8 ms
IV	G-1456	12 μm	800 μs (±200 V)	2 ms

From the preceding data, several general observations can be made:

(1) In all cases, the rise time for the TLSM effect occurs within less than 1.5 ms, with a rise time of 80–100 μs observed for cell I (ZLI 4003, 25 μm pathlength) at an applied voltage of ±200 V.

(2) The decay time for all of the measured cells ranges from approximately 1-6 ms, which is nearly 5–100 times faster than that observed for dynamic scattering cells of equivalent pathlength (25–100 ms).

(3) Further improvements in the decay times should be possible by use of an unsymmetrical driving waveform (e.g., an unsymmetrical square wave or a shaped positive and negative pulse train).

It is also important to note that no attempt was made to optimize the alignment condition for the liquid crystal materials used or to make adjustments in mixture compositions that would maximize the birefringence or spontaneous polarization of the materials used. For applications in the infrared region, a material with as high a birefringence as possible would be desirable in order to attain the maximum amount of scattering.

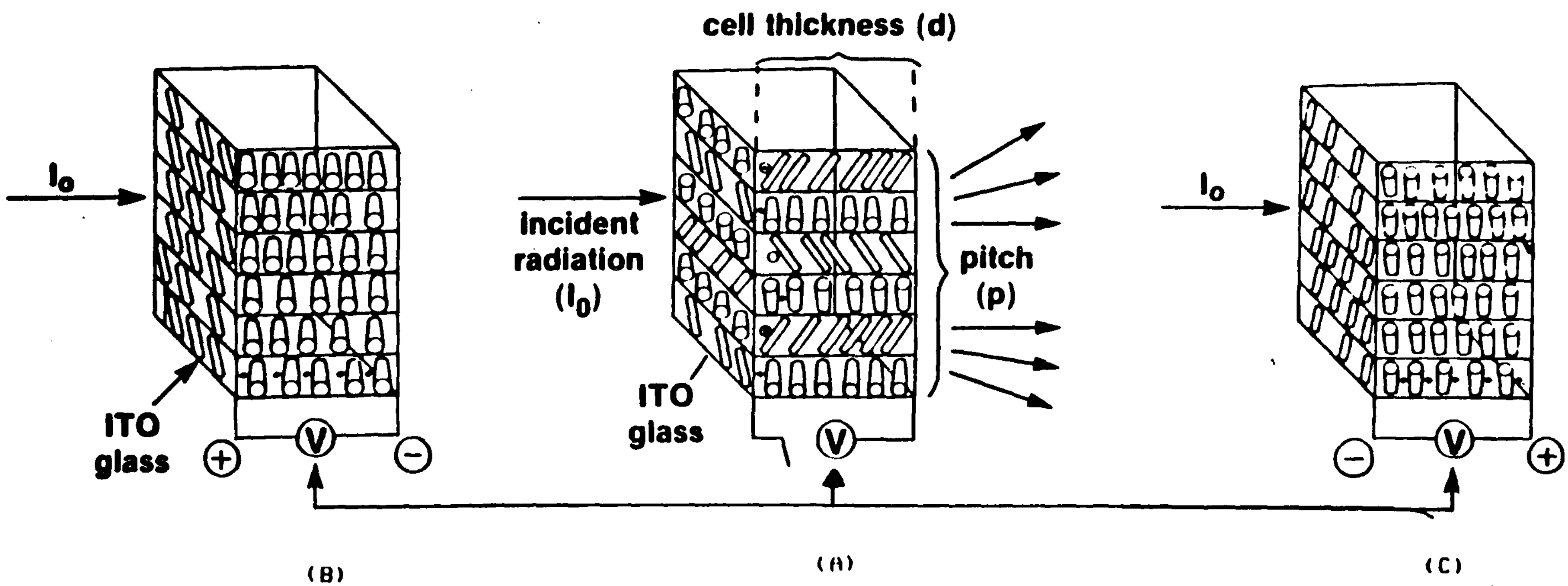
III. IR TRANSMISSION CHARACTERISTICS OF FERROELECTRIC LIQUID CRYSTALS

The transmission of several ferroelectric liquid crystal materials in the infrared was determined using a Nicolet 20 SXC Fourier Transform Infrared Spectrometer. The sample cell was a Wilks Model VR-6 variable path cell with KBr substrates. The path length of the cell was adjusted to 10 μm and the calibration checked by an interference fringe method. The IR spectrum of a single KBR window of the same thickness as the substrates used in the variable path cell was subtracted from subsequent scans of the unaligned bulk liquid crystal materials to correct for Fresnel losses. In addition to the two materials used previously for the TLSM electro-optic measurements, a third mixture (D 78283) prepared in-house from compounds supplied by Displaytech Corp. was also evaluated. The infrared transmission spectra for unaligned 10-μm path lengths of the three ferroelectric liquid crystal mixtures in the 8–12 μm region is shown in Figs. 5–7. For comparison, an infrared spectrum of the well known nematic liquid crystal material E7 was collected under the same conditions; its transmission characteristics in the 8–12 μm region are shown in Fig. 8. An examination of the infrared spectra indicates that the ferroelectric smectic liquid crystal materials exhibit stronger absorption bands in the 8–10 μm region than do their nematic counterparts. Since absorptions in this region are due primarily to carbon-carbon and carbon-oxygen single bond stretching vibrations, the increased strength of these absorption bands can be accounted for by the larger number of C-C bonds in the long terminal alkyl and alkoxy chains of smectic liquid crystal compounds as compared to the shorter terminal groups found in nematic materials. Between 10 and 11.5 μm, however, transmission windows in excess of 80% are available in several of the ferroelectric liquid crystal mixtures which have been examined. Since only mixtures of compounds have been evaluated to date, it is not yet clear whether the degree of absorption observed is due to all of the components of the mixture or only certain compounds. By careful screening of individual compounds for their absorption characteristics in the 8–12 μm region and blending of these selected materials to form eutectic mixtures, it may be possible to effect an increase in mid-infrared transmission of ferroelectric materials in selected areas of interest, such as the 10–11.5 μm region.

IV. SUMMARY

From these initial investigations, it appears that the TLSM effect in ferroelectric liquid crystals offers considerable potential for use in an IR shutter-chopper device. The particular advantage of this effect over the previous approach utilizing the dynamic scattering effect in nematic liquid crystals lies in the inherently rapid rise and decay times of the TLSM mode, along with the potential ability to control the length of the decay time by adjusting the ferroelectric helix pitch and the shape of the driving voltage waveform. A key issue in the practical realization of the TLSM mode for the above mentioned application will be the selection and/or preparation of appropriate ferroelectric liquid crystal materials which exhibit both high birefringence to enhance scattering and good optical transparency in the mid-infrared region.

Figure 1: Transient Light Scattering Mode (TLSM) in Ferroelectric Liquid Crystals

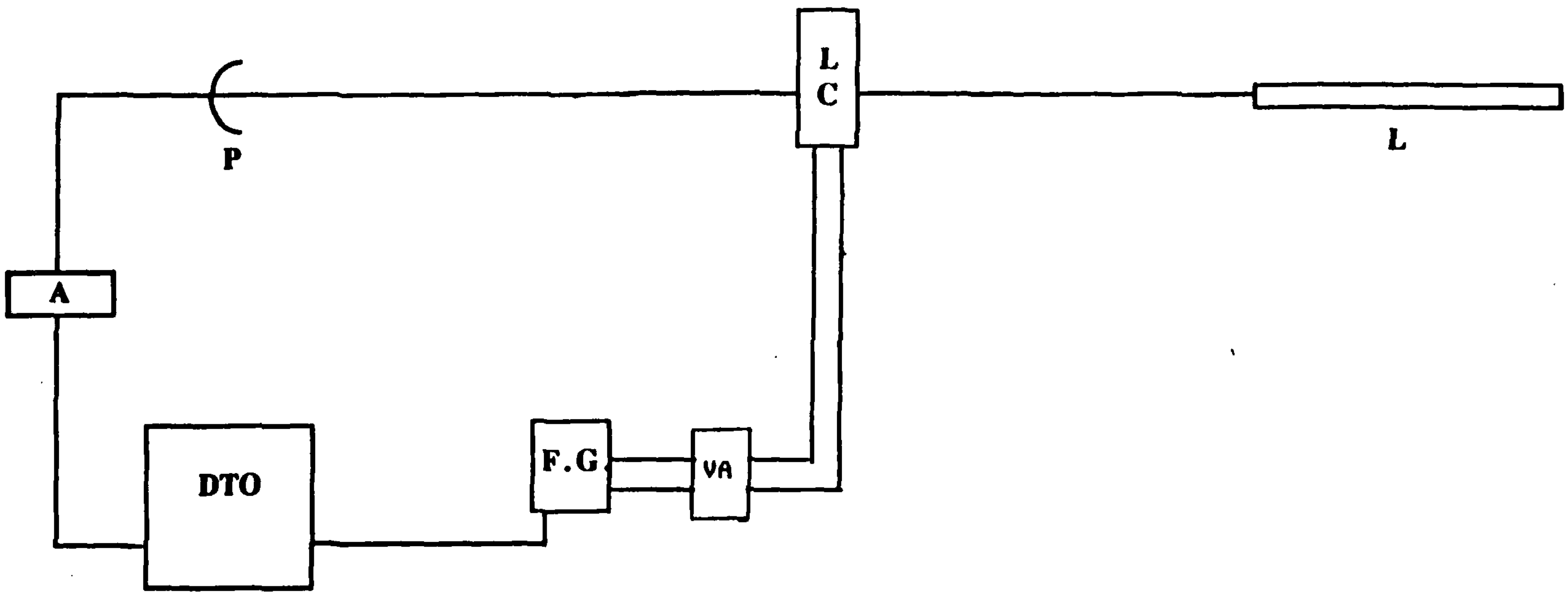


(A) With no field applied, the helix axis lies parallel to the substrates, producing a scattering texture.

(B) Application of a positive DC field causes helix unwinding, rendering the cell transparent.

(C) Reversal of field polarity causes the cell to pass from state (B) (transmissive) through state (A) (scattering) to state (C) (transmissive), producing the transient scattering effect.

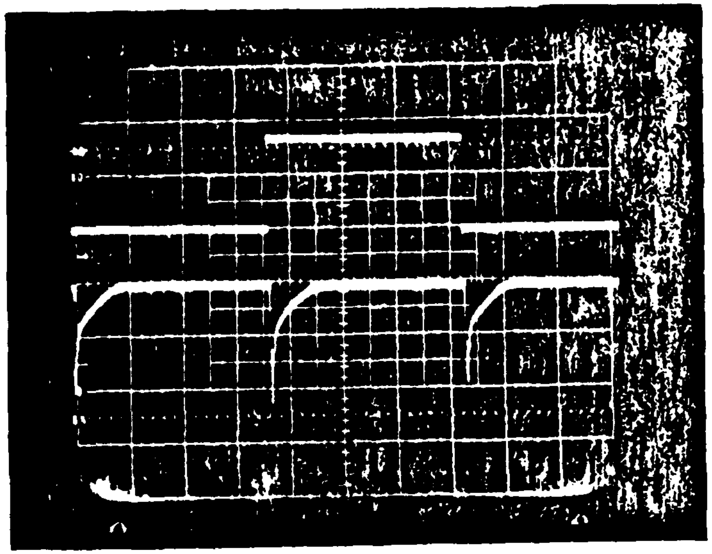
Figure 2: Electro-optic Test Setup



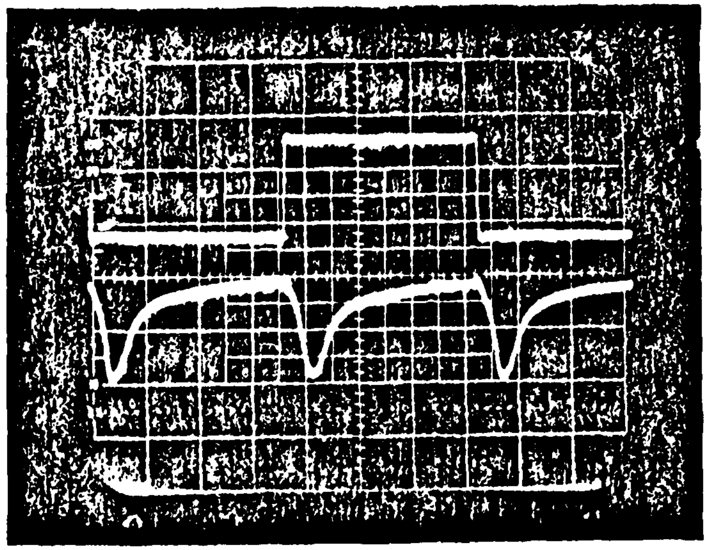
L	=	HeNe laser
LC	=	Liquid crystal cell
P	=	Photodiode
A	=	Amplifier
FG	=	Kron-Hite function generator
VA	=	Voltage Amplifier
DTO	=	Dual trace oscilloscope

Figure 3: TLSM Response in ZLI-4003

A



B

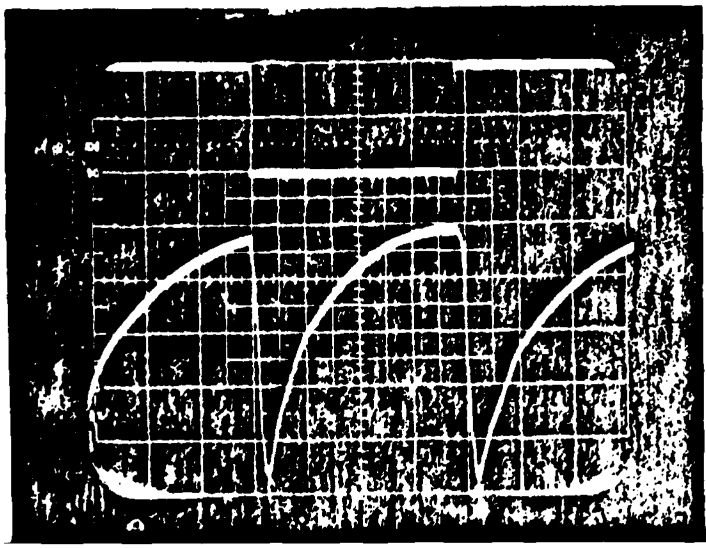


Cell I
Pathlength: 25 μm

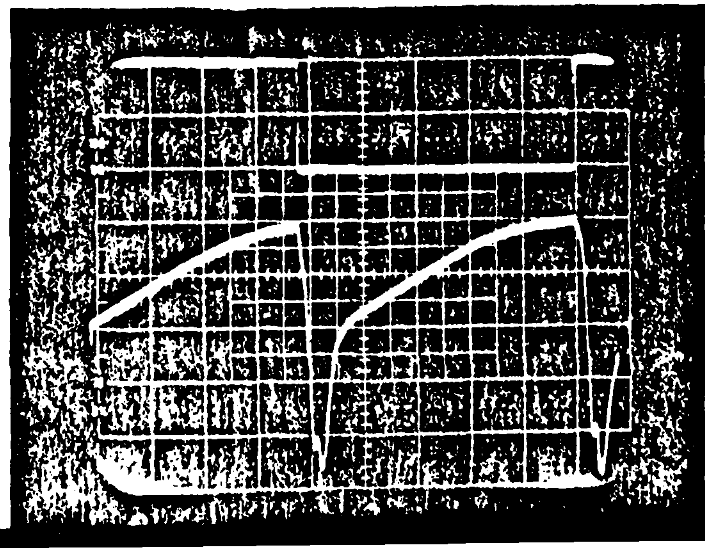
a. Drive Voltage: ±200 V
Time Axis: 2 ms/div

b. Drive Voltage: ±200 V
Time Axis: 200 μs/div

C



D



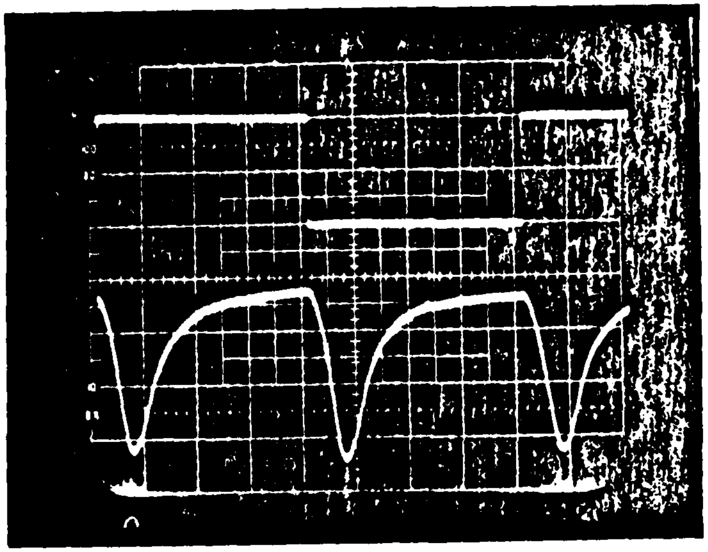
Cell III
Pathlength: 50 μm

c. Drive Voltage: ±80 V
Time Axis: 2 ms/div

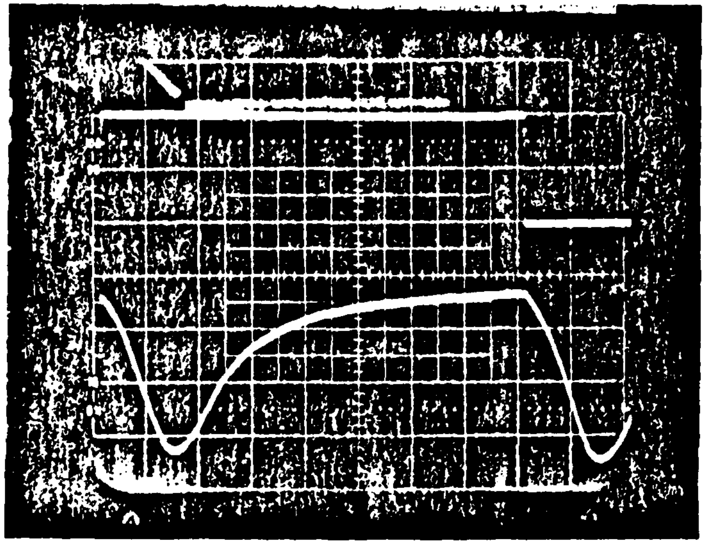
d. Drive Voltage: ±200 V
Time Axis: 500 μs/div

Figure 4: TLSM Response in G-1456

A



B

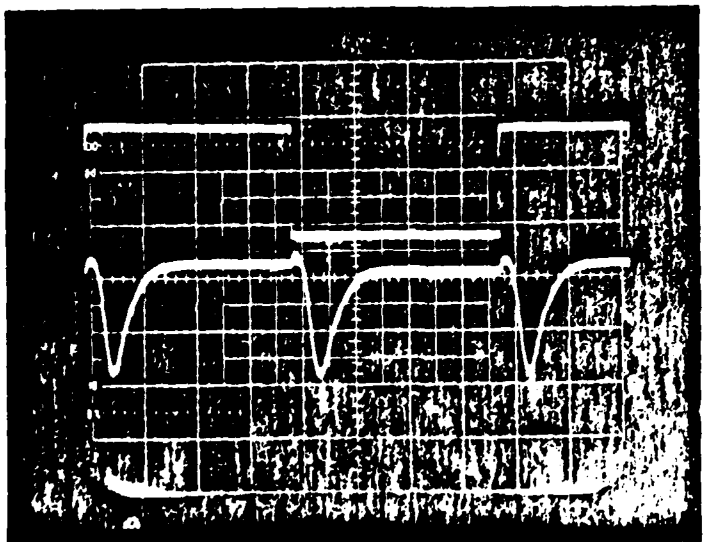


Cell II
Pathlength: 25 μm

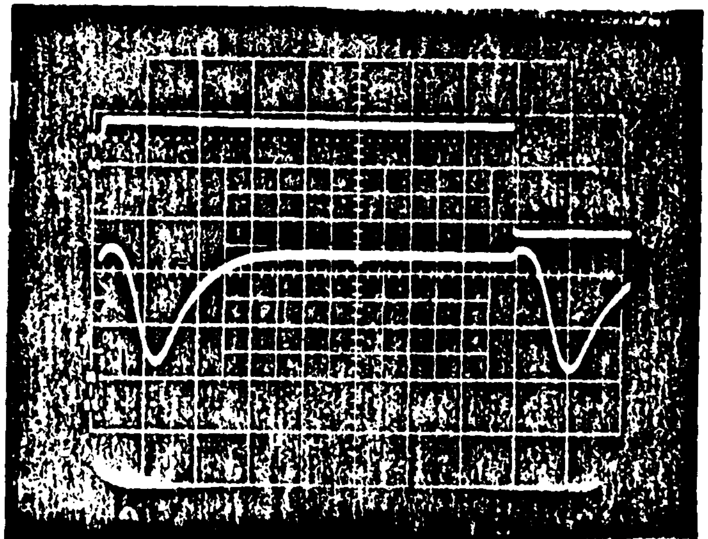
a. Drive Voltage: ±200 V
Time Axis: 2 ms/div

b. Drive Voltage: ±200 V
Time Axis: 1 ms/div

C



D



Cell IV
Pathlength: 12 μm

c. Drive Voltage: ±200 V
Time Axis: 2 ms/div

d. Drive Voltage: ±200 V
Time Axis: 1 ms/div

Figure 5: IR transmission of D-78182 in the 8–12 μm region

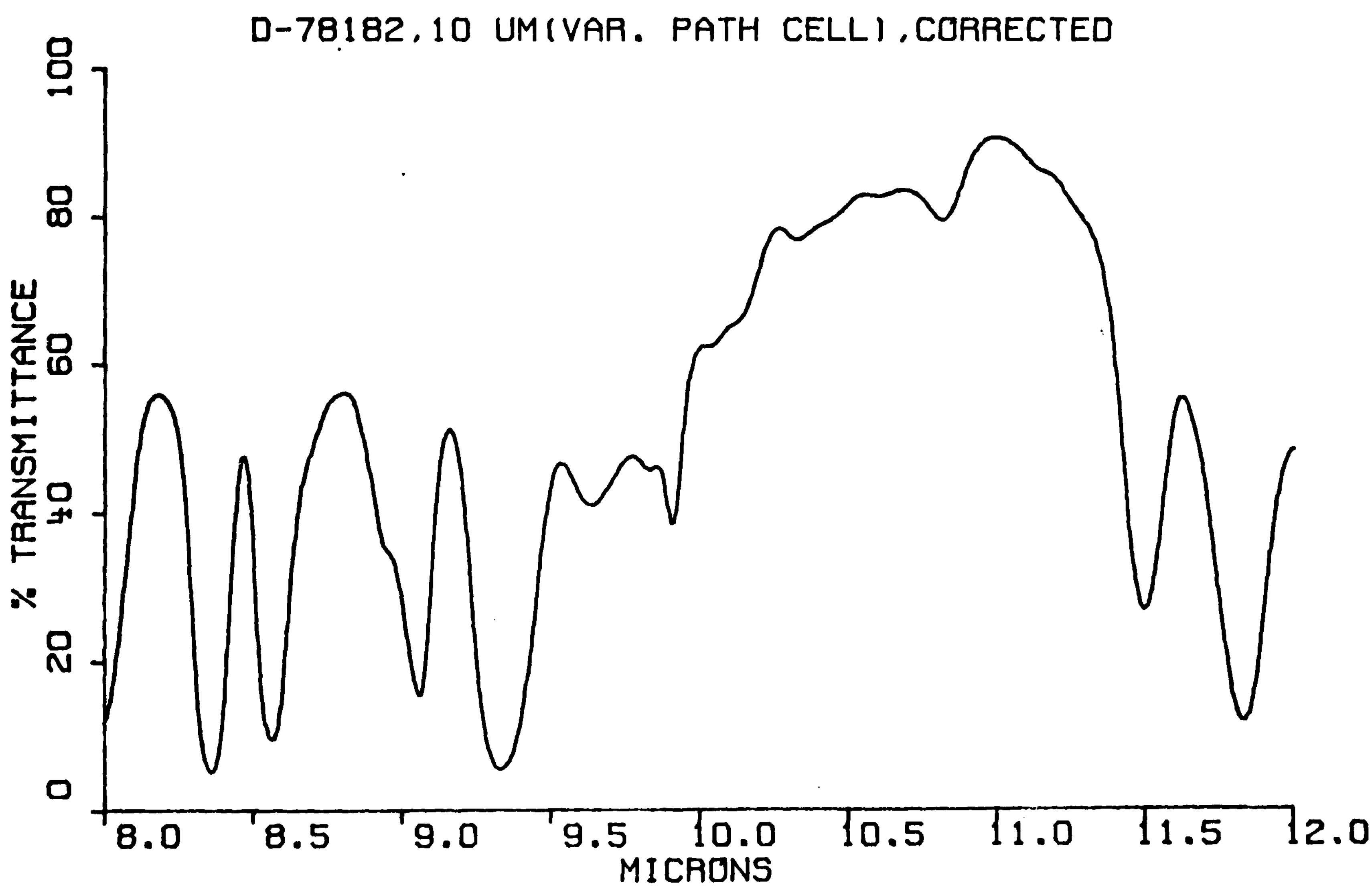


Figure 6: IR transmission of G-1456 in the 8–12 μm region

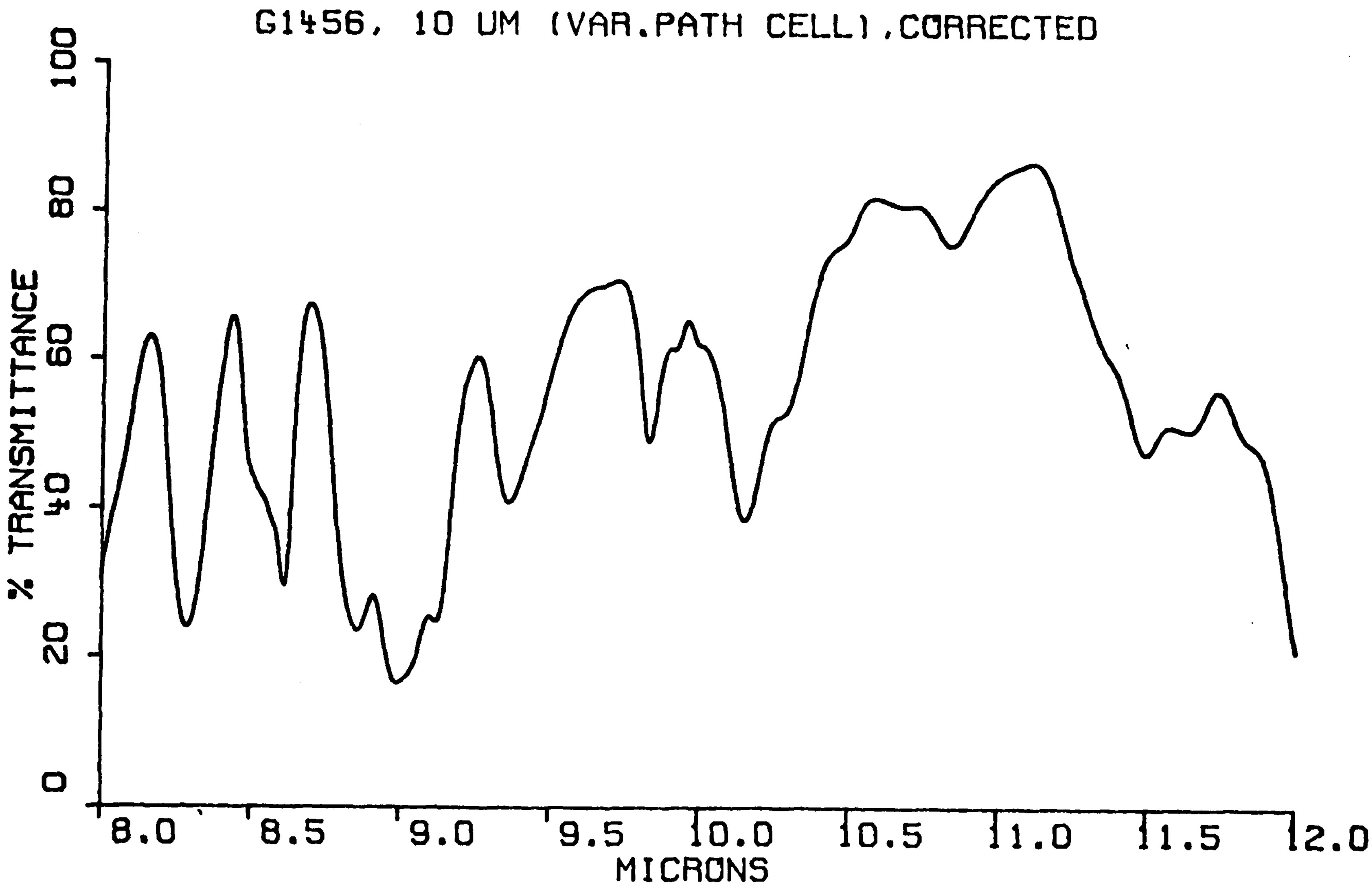


Figure 7: IR transmission of ZLI-4003 in the 8–12 μm region

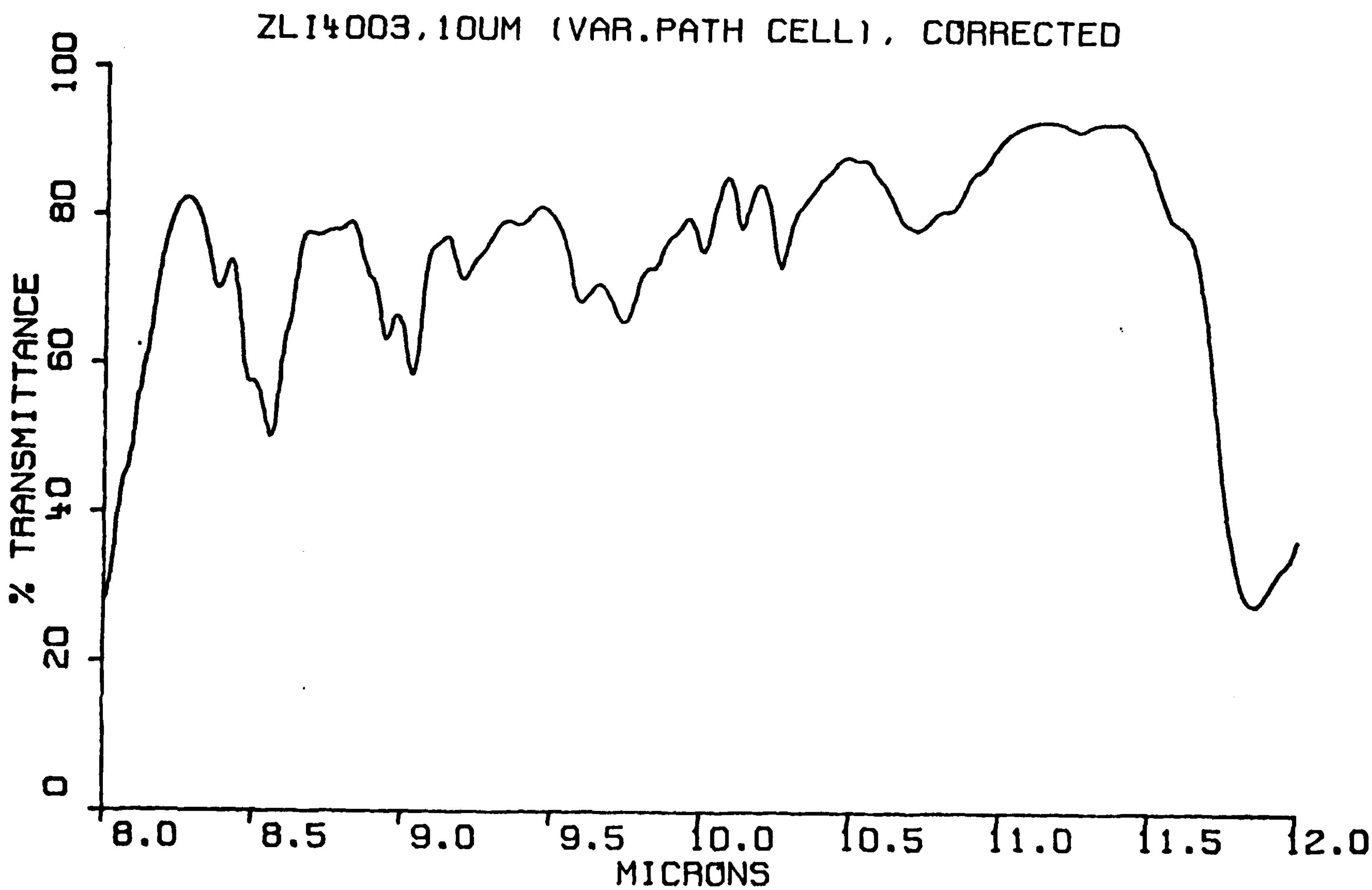


Figure 8: IR transmission of the nematic liquid crystal E-7 in the 8–12 μm region